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INDEPENDENT EVALUATION OF THE GAM EX5ALN MINIATURE LINE-NARROWED KRF EXCIMER LASER

Bradley R. Arnold
Nicole Couturier
Castle Gushen
Corryn Wheatley

UNIVERSITY OF MARYLAND BALTIMORE COUNTY
Baltimore, MD 21250

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14. ABSTRACT
The scope of this effort was to determine how the GAM Ex5ALN Line-Narrowed Ruggedized KrF Excimer Laser operates compared to the manufacturer's specifications. Evaluation criteria included measurements of the output power, pulse-to-pulse stability, laser pulse length, bandwidth, trigger jitter, pulse profile, and fill-gas lifetime. In general, the laser performs satisfactorily and in accord with the manufacturer's specifications. Principal recommendations are for the manufacturer to resolve software problems and provide more complete instructions for installation, servicing, and operation.

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PREFACE

The work described in this report was performed at the request of the U.S Army Edgewood Chemical Biological Center (ECBC) in support of the ongoing Chemical Surface Detector Program. The work was started in September 2016 and completed in December 2016.

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INDEPENDENT EVALUATION OF THE GAM EX5ALN MINIATURE LINE-NARROWED KRF EXCIMER LASER

1. INTRODUCTION

1.1. Objective

The objective of this effort was to determine if the GAM Ex5ALN miniaturized, line-narrowed, and ruggedized KrF excimer laser operates according to the manufacturer's specifications. Evaluation criteria included measurements of the output power, pulse-to-pulse stability, laser pulse length, bandwidth, trigger jitter, pulse profile, and fill-gas lifetime. The evaluations were performed by members of the chemistry and biochemistry department at the University of Maryland at Baltimore County (UMBC).

1.2 Overview

High-power, high-repetition rate excimer lasers are available from several US manufacturers. These systems are specifically designed for materials processing applications where the bandwidth of the output pulse is not a critical issue; excimer lasers have a fundamental bandwidth of ~2 nm. The desire to utilize high-power high-repetition rate laser systems for spectroscopy applications, where small bandwidth is important, has resulted in a need for line-narrowed excimer lasers. This niche market has been occupied by GAM Lasers Inc. The following report contains an independent evaluation of a GAM Ex5ALN miniature line-narrowed krypton fluoride (KrF) laser operating at 248 nm as a potential excitation source for spectroscopic measurements.

The scope of this effort was focused to determine if the GAM laser operates according to the manufacturer's specifications. As such, the operational aspects of the laser control software were not tested except in so far as the software was needed to control the operation of the laser itself. Nevertheless, the report provides some discussion on issues associated with the software as a result of this investigation. The measurement and diagnostic aspects of the software were largely left unexplored. The laser was operated in the constant voltage mode using continuous internal triggering. No other modes of operation were tested.

The ease of installation of the hardware and control software, day-to-day operation and maintenance as well as general operational characteristics of the laser system were tested to determine if the laser operated according to specifications. Evaluation criteria included measurements of the output power, pulse-to-pulse stability, laser pulse length, bandwidth, trigger jitter, pulse profile, and fill-gas lifetime. The specifications for the line narrowed Ex5ALN KrF excimer laser system according to the manufacturer are collected in Table 1.

Table 1. Ex5ALN Manufacturer's Specifications

Wavelength:	248 nm
Line width	0.020 nm
Energy per pulse	15 mJ
Pulse length	8 ns
Line shape	Gaussian
Beam shape	3 × 6 mm
Divergence	1×2 mRad full angle
Average Power	0.3 W @25 Hz
	2.5 W @250 Hz
Stability	< ±3% (1σ)
Max Rep Rate	250 pulses per second
Timing jitter	±2 ns (1σ)
Fill life	18 M pulses
Optics service	100 M pulses
Shelf life	10 days to 50% energy
Cooling	Air
Tube service	1000 million pulses
Weight	16 kg

2. TEST EQUIPMENT AND PERFORMANCE

Descriptions of the equipment used in this study and performance include:

i) Power meter/sensor head. A Thorlabs GmbH PM100D optical power meter SN P0014267 (calibration due Oct 2017) with a S350C detection head SN 160446 (calibration due Apr 2017). Both the meter and power head were free from visible damage and were operating correctly according to manufacturer's specifications. The meter was wavelength corrected to 248 nm for the purposes of these tests. A second energy meter, supplied by GAM, was also used. This additional detection system was an Ophir Smart Heat to USB Interface PN 7201200 (calibration due Oct 2017) with a pyroelectric detector head PE10-C ROHS SN 788778 (calibration due June 2017). The interface and detector head had no visible damage and were functioning according to manufacturer's specifications.

ii) Single shot detection and timing. A biased Si diode detector (Thorlabs DET10A) was connected to a Tektronix TDS 2001c oscilloscope (with dual time-base capability) using 50 Ω termination. This detector system has ~1 ns rise and fall times and was used to measure the laser pulse width and determine the trigger jitter.

iii) Wavelength detection. The laser output wavelength and bandwidth were measured using an Acton 2300i spectrograph equipped with a Roper Intensified charge-coupled device (ICCD) array detector. This combination allowed ca 0.1 nm per pixel (0.3 nm resolution). The wavelength of the spectrograph system was calibrated using the atomic Hg emission line at 253.652 nm from a low-pressure UVP pen ray lamp and matching power supply.

iv) Pulse profiler. A camera-based beam profiler system (Thorlabs BC106N-UV) was used to examine the laser beam emission shape and intensity profile.

2.1 Installation

Installation of the ruggedized version of the Ex5ALN KrF excimer laser included little more than removing the laser from the shipping crate, leveling it on the laser table, attaching the KrF premix gas bottle and plugging the laser in. The serial number of the laser delivered to UMBC was Ex5AR/500-101 and the on-board laser counter display was set to 0. If this system was tested by GAM (or others) the number of preliminary laser shots is unknown.

The laser cannot be operated manually and should be connected to a computer operating Windows 7 through a PCI slotted data card (Advantech PCI-1711U) and a USB based energy monitor (Ophir "Smart Heat to USB Interface"). Both the interface and detector head appeared to be in good working order with no visible damage. Installation of these components and the control software was accomplished in several steps following a procedure supplied by the laser manufacture. Overall, the process was straightforward and completed in a few minutes. A description of what each step was designed to accomplish was absent but would be helpful to the installer.

2.2. Software

The control software itself was serviceable although numerous examples of poor programming practices were noted. The main operational screen allows the operator to select operational modes (constant voltage or constant energy) and to adjust the repetition rate and discharge voltage. The laser can be operated from this screen with minimal difficulty. The installed version appeared to be significantly different from that described in the supplied manuals. The manuals for the laser system also seem to have multiple inconsistencies, not only when compared with the software, but also within different sections of the manual itself (e.g., several thyratron voltage settings appear in different sections of the manual). As a result, the operator was left with conflicting information and uncertainty about the correct operating conditions for the system. Functional errors in the software included the disabled tabs and buttons that clutter the panels. Information on these panels was not updated correctly (e.g., shots per fill and total shots are not stored correctly and appear to contain random data, the lock function on the fill page does not update correctly, the time to completion display on the refill panel is incorrect, etc). Additionally the software components would lock up and be rendered useless (e.g., pulse energy monitor locks up if attempting to utilize some of its functions). Some of the software controlled procedures were poorly described. For example, the procedure for pumping out the gas manifold to exchange the pre-mix bottle required the operator to ignore software requested service operations. Also ignored was the indication to "Make certain the laser head manual valve is open". A low pressure warning was also ignored). It would benefit users greatly to have these inconsistencies minimized. While these programming errors were a nuisance they did not prevent the laser from being tested. As such they were considered to be outside the scope of this study.

2.3 Laser Setup

2.3.1 Initial Setup

With the hardware and software installed, the next procedure that needed to be completed before the laser could be used was to fill the laser with premixed gas. The GAM procedure for attaching the premix gas bottle should be described more accurately and in more detail. This procedure is critical to the performance of the laser system and should be completed correctly to avoid contamination of the laser cavity and residual gas bottle with air. In the specific case of the system delivered to UMBC, a leak was detected during the installation process. It was determined that the leak originated in the value stem seal on the premix gas bottle supplied by Linde and not in the gas manifold of the GAM laser. It was clear that GAM was not responsible for this leak. Nonetheless, the procedure for detecting such leaks and avoiding contamination of the laser system should include such possibilities, and best practices for avoiding contamination should be described by GAM in the laser manual.

Initial setup of the laser uncovered a discrepancy between the on-board energy meter and a user supplied (NIST calibrated) power meter. Further analysis suggested the error was due to a poorly calibrated on-board monitor that over-estimated the energy per pulse. Details of the energy monitoring system tests will be discussed in detail in the Energy Stability section of this report.

Installation of the system hardware, software, and filling the laser system required about 2 h to complete under the supervision of a manufacturer's representative. Additional time was needed to track down the leak, as described above, but the procedure eventually ended with the system operating near the manufacture's specified maximum power output. If the manuals and installation procedures were clearly documented, and the software improved, it could be possible for most users to install this system on their own. Unfortunately, with the documentation in its current state, it is not clear that the laser would have been correctly installed in the absence of a qualified guide. As the work force becomes more reliant on digital communication, perhaps a simple downloadable video (YouTube) could be prepared to facilitate the installation procedures. At a minimum, far better documentation of these procedures is required.

2.3.2. Thyratron Burn-in

Initial testing of the laser system revealed poor shot-to-shot stability which grew more unstable with continued use. It was concluded that the thyratron voltage needed to be adjusted. Review of the advanced [diagnostics] panel in the software showed the voltage was initially set to 6.23 volts. Increasing the voltage to 6.28 volts helped stabilize the system for a short period of time. The voltage was increase two additional times to 6.33 and finally 6.38 volts after several days of operation. In all, more than 15 M shots were completed before long-term, consistent, firing of the system was achieved. It would be beneficial for GAM to complete the thyratron burn-in before shipping the laser or alerting the end user that a burn-in period is expected and that thyratron voltage adjustments may be necessary. The remaining test results described in this report were all completed after the thyratron voltage adjustments were performed (after more than 15 M shots of the laser were completed).

2.3.3. Daily Start-Up Procedure

The procedure adopted to start the laser system for this study is based on the procedure suggested by GAM. Specifically, the laser was powered up and the software started. The system automatically starts the thyratron and etalon heaters and remains on hold for four minutes while the system components reach stable temperatures. After the four-minute warm-up period was completed, the laser could be started, although we typically waited a few more minutes (~ 10 min) before starting the laser. Allowing the laser to run at 12 kV and 20 Hertz (Hz) for a few additional minutes before increasing the voltage or repetition rate allowed the system to complete its warm-up. In all, about 15-20 minutes would elapse before measurements would be taken. The laser was operated in constant voltage and continuous modes. No tests of the constant energy mode were performed.

2.3.4. System Refill Procedure

Refill procedures were completed using the refill screen of the laser operation software. An attempt to use the software "full refill" procedure resulted in the on-board vacuum pump timing out before the low pressure limit was reached. At that point, the software shuts down the pump. This practice leaves the laser in a critical condition below atmospheric pressure, which should be avoided at all cost. Additional attempts to fully evacuate the system failed because restarting the pump requires partial refill of the laser system. Several attempts to complete the pump-out procedure subsequently failed. A partial refill was completed to bring the laser back to a useable state.

Our tests concluded that two consecutive 60% refill operations were sufficient to recharge the system back to full operating condition. This condition will be described as "fresh fill" throughout this report. To complete a fresh fill, one 60% refill would be completed and followed by a few minutes of operation (alternatively running the blower for a few minutes) before the second 60% refill would be completed. Additional partial refills did not improve operation and were subsequently deemed unnecessary. It should be noted that the test system was refilled when the laser output degraded by 50% and frequently sooner. Severely degraded initial conditions, such as over-use or long term storage, may require more extreme refill procedures to be employed.

The fresh fill, using two consecutive 60% refill procedures, was adopted as the routine refill procedure for this study. Each fresh fill procedure used ~70 psi of premix per refill. More than 25 refills are possible using 1 premix bottle. The procedure as described above takes about 5 min to complete although two 60% refills without running the system in-between could be completed in less than 2 min.

2.3.5 General Operation

The laser was evaluated for general operation to understand how prolonged use influenced the laser output. The stability of the laser under conditions of high discharge voltages and rapid firing rates was examined during these tests. The laser was capable of operating at 15 kV discharge voltages and 500 Hz operation for short time periods. Long term use (e.g., longer

than 1 hour) at 14 kV at 200 Hz causes the system to heat up and develop high laser cavity pressure (> 4100 torr). Operational characteristics degraded rapidly under these conditions and the laser firing became erratic. Allowing the laser to cool back to room temperature restored normal operation although at a degraded output energy. Preliminary testing showed that laser operation was less sensitive to repetition rate than discharge voltage, and the total number of pulses accumulated was an important predictor of laser operation. Higher discharge voltages degraded the laser output more rapidly than lower voltages and fewer accumulated pulses could be obtained between fills. The laser performed best between 50 Hz and 150 Hz. Higher repetition rates caused overheating and reduced pulse-to-pulse stability. Lower pulse energies and reduced stability were observed at lower repetition rates as well. Tests were conducted under conditions to avoid overheating of the system. The manufacturer suggested long term stability tests be carried out at 12 kV and 20 Hz. The majority of tests were conducted at 100 Hz. Figure 1 graphically summarizes the relationship between repetition rate and average power output at five discharge voltages between 12 and 14 kV.

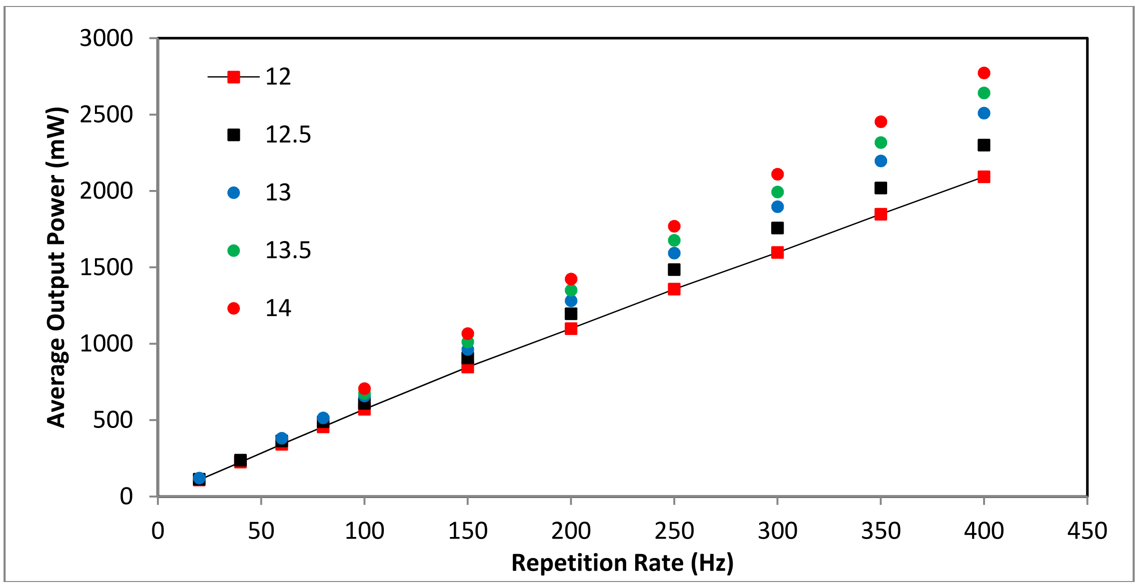

Figure 1. Ex5ALN KrF laser average output power as a function of repetition rate for discharge voltages ranging from 12 kV to 14 kV for short term use.

2.3.6. Wavelength Stability

Wavelength stability was tested using an Acton 2300i spectrograph equipped with a Roper ICCD array detector with a resolution of 0.1 nm per pixel. The laser pulse was recorded with the 253.652-nm Hg atomic emission line as a calibration source as shown in Figure 2. A slight shift in laser wavelength of < 0.1 nm was occasionally observed at the onset of the warm-up procedure as the etalon reached its normal operating temperature (i.e., the first 10-15 min of operation). After the system reached its normal operating temperature, the laser output was stable at 248.7 nm. The output wavelength did not change with discharge voltage or with degradation of the fill gas but remained stable over the duration of the tests (over 43 M shots). Three examples taken during long-term testing of the system are shown in Figure 2 below. The

bandwidth of the laser system was designed to be significantly narrower than the resolution of the spectrograph; as a result, a detailed analysis of the bandwidth could not be performed.

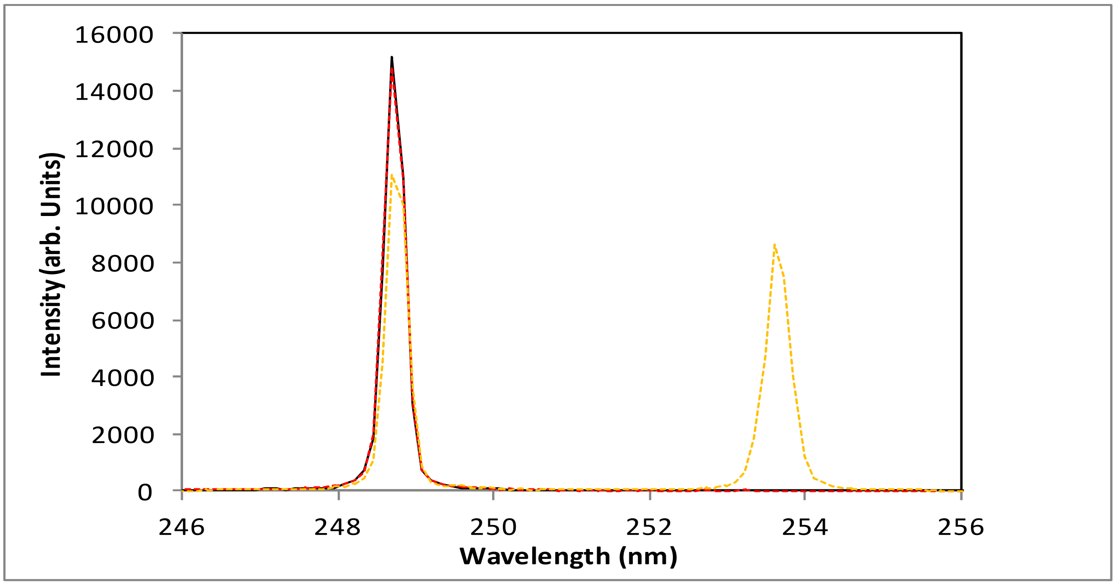

Figure 2. Ex5ALN KrF laser wavelength study. The laser output was recorded at 248.7 nm relative to the Hg atomic emission at 253.7 nm.

2.3.7. Pulse Width and Repetition Rate

Laser pulse width, repetition rate, and trigger jitter were monitored using a biased Si diode detector connected to a Tektronix digital oscilloscope using 50 Ω termination. This detector system has ~1 ns rise and fall times. The repetition rates measured with this system were found to be within 0.001% of the value listed in the laser control software. The control software appears to drop a single pulse at a set rate. Specifically, a dropped pulse was observed after every sixth screen update. This dropped pulse could be observed using the software pulse counter as well as heard as an audible aberration in the trigger frequency. The cause of this dropped pulse is not clear at this time although it is likely part of a software-derived maintenance cycle (a round-off error or system memory access within the program). Its occurrence does not adversely affect the output characteristics of the laser system.

Typical pulse length variation is shown in Figure 3 for set periods during a full day operating at 14 kV and 100 Hz. Pulse width measurements reveal that the pulse width varies with fill conditions. Fresh refill conditions result in pulse lengths as long as 10.5 ns. The pulse narrows to near 9 ns and continues to narrow to as short as 8.5 ns as the pulse energy degrades to 50% of the fresh fill condition.

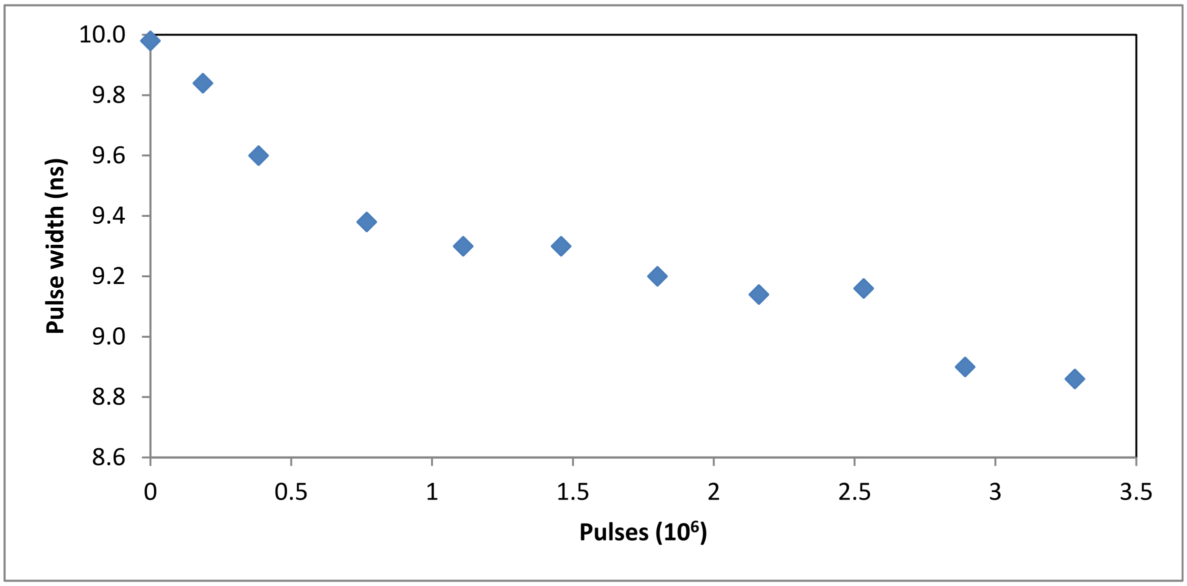

Figure 3. Ex5ALN KrF laser pulse width versus accumulated pulses for 14 kV discharge at 100 Hz.

2.3.8. Laser Timing Jitter

Laser pulse delay was measured using to the sync out pulse on the excimer laser. Trigger jitter using external triggering was not tested in this study. Typical delays ranged between 880 to 950 ns and depended on the discharge voltage, fill gas pressure, and laser operating temperature. A typical series of pulse timing events is shown in Figure 4 for a 14 kV discharge voltage operating at 100 Hz. As shown in the figure, the earliest pulse was recorded before the laser reached its equilibrated operating temperature. Such early pulses rapidly shifted to the thermally equilibrated position although sometimes shifting to longer delays, as shown, but shifts to shorter delays were also observed depending upon the discharge voltage. These early shifts could be as much as 30 ns or more. Subsequent traces shown in the figure occur in two distinct groupings. Typical pulse-to-pulse jitter was observed to be less than 2 ns centered at 906 ns (~80% of the pulses) although a second grouping of pulses occurred about 3 ns earlier (~20% of the pulses). The laser jumped between these two stable conditions on a regular basis.

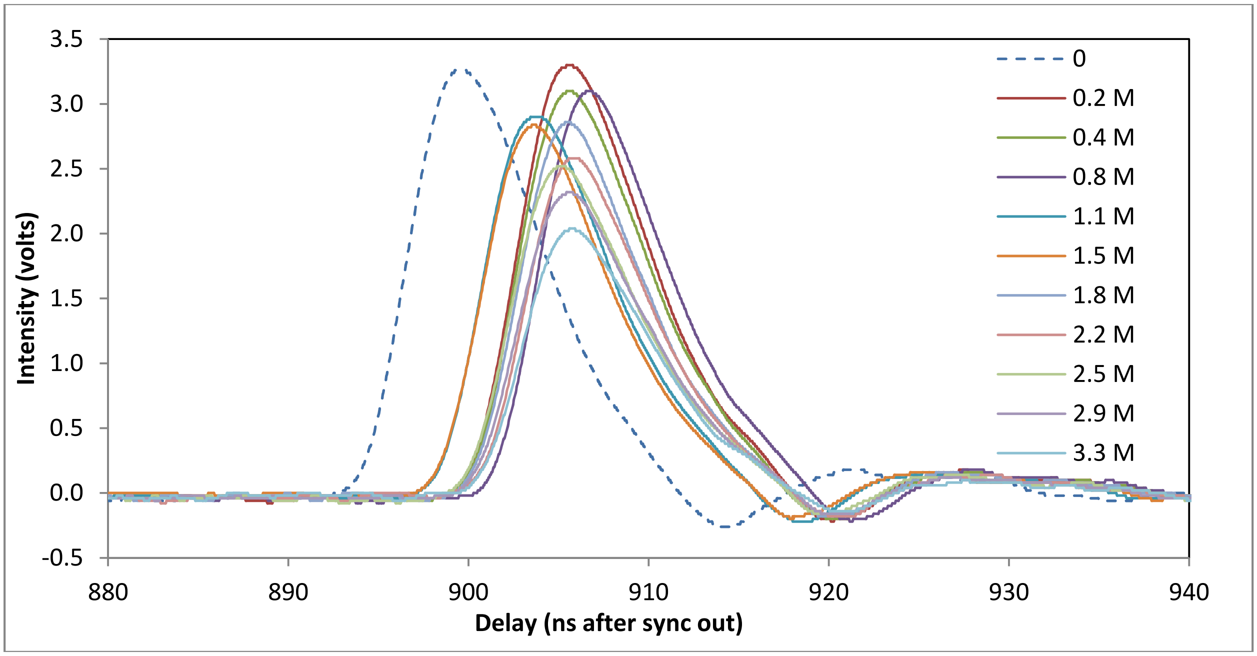

Figure 4. Ex5ALN KrF laser timing jitter of laser pulses observed during prolonged operation at 100 Hz.

2.3.9. Energy Stability

Calibration of the on-board energy monitor (the Ophir USB Interface with a pyroelectric detector head) was checked using a customer-supplied power meter (the Thorlabs optical power meter with a S350C detection head SN). The energy monitor could be compared with the power meter based on the known trigger rate (i.e., energy per pulse = power/trigger rate). Direct comparison revealed that the on-board monitor consistently over-estimated the output energy by 20%. The on-board meter reported energy bleeding through the laser cavity rear mirror using a GAM supplied calibration factor. When the energy monitor is removed from the rear panel of the laser and placed in the laser beam to measure the output energy directly (using the GAM supplied Ophir software), the reported energy readings are 2-3% LOWER than indicated by the user-supplied power meter. Differences of a few percent were considered acceptable given the differences between the detection mechanisms (pyroelectric vs. photothermal) and that the energy meter was nearing its upper detection limit. The difference between the on-board meter and the customer supplied power meter increased with use of the laser system. Presumably the laser output coupler degrades in performance or the rear mirror becomes less reflective. Regardless of the true reason for the discrepancy between the meter readings, the customer-supplied power meter was considered correct and was then used for all of the absolute power measurements recorded in this report. Energy per pulse readings were calculated from the recorded power measurements and the repetition rates when necessary.

Pulse-to-pulse stability was monitored with the on-board energy monitor independently as described below. The pulse-to-pulse variation in energy was recorded, and a standard deviation (σ) of near $\sigma = \pm 1.5\%$ under fresh fill conditions was observed. As the fill gas degraded the pulse-to-pulse reproducibility also degraded; after degradation of the pulse energies by 50%, the pulse-to-pulse reproducibility fell to $\sigma = \pm 2\text{-}3\%$. When the laser degraded to 30% of

its fresh fill energy output the pulse-to-pulse reproducibility fell significantly to σ > ±15%. Discharge energies between 12 - 14 kV with rep rates up to 200 Hz had similar responses. Figure 5 shows the cumulative plots of 10 pulses collected in rapid succession after 8 M pulses at 12 kV and 100 Hz (i.e., after nearly 50% degradation). The calculated reproducibility was σ = ±2.3% as shown. Notice the two distinct groupings of trigger delayed pulses separated by ~3 ns. As described above, the trigger jitter jumped between these two stable states on a regular basis.

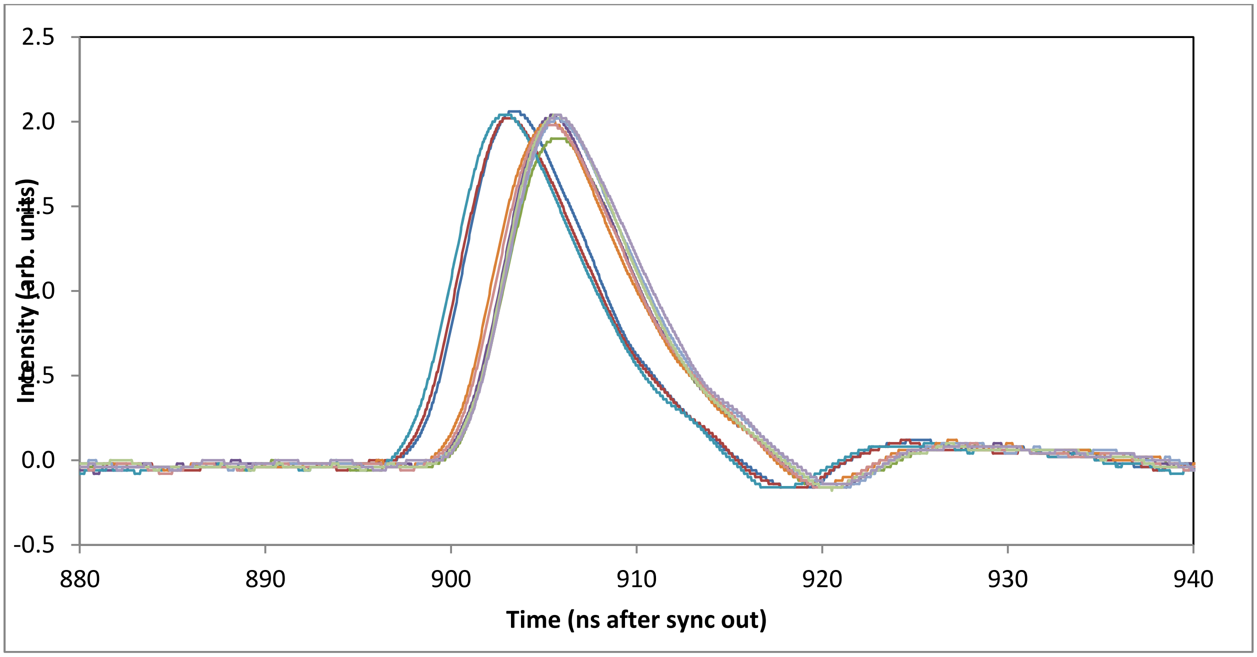

Figure 5. Ex5ALN KrF laser pulse-to-pulse stability (σ = 2.3%) and trigger jitter of less than 1 ns within two distinct delay groups 3 ns apart. Pulses were collected in rapid succession after 8 M accumulated pulses at 12 kV and 100 Hz.

2.3.10 Fill Durability

To determine the useful lifetime of the fill gas, the total number of accumulated pulses before the laser performance degraded to 50% of the fresh fill output were measured. The laser was operated continuously at 12, 13, and 14 kV discharge voltages and 100 Hz repetition rates. The 14 kV test result is shown in Figure 6 where the laser was fired for ca. 9 hours (blue), shut down overnight and then restarted (following the daily warm-up period) and fired for another 9 hours (red) until the energy decreased to 50% of its initial output. Using 14 kV discharge voltage at 100 Hz, the fill lifetime was about 7 M shots, as seen in Figure 6, but for 13 kV the lifetime was estimated to be 10 M and at 12 kV over 17 M shots could be expected before degradation of the laser power to 50%. The degradation rate of 17 M (at 12 kV) is in agreement with the manufacturer's specifications.

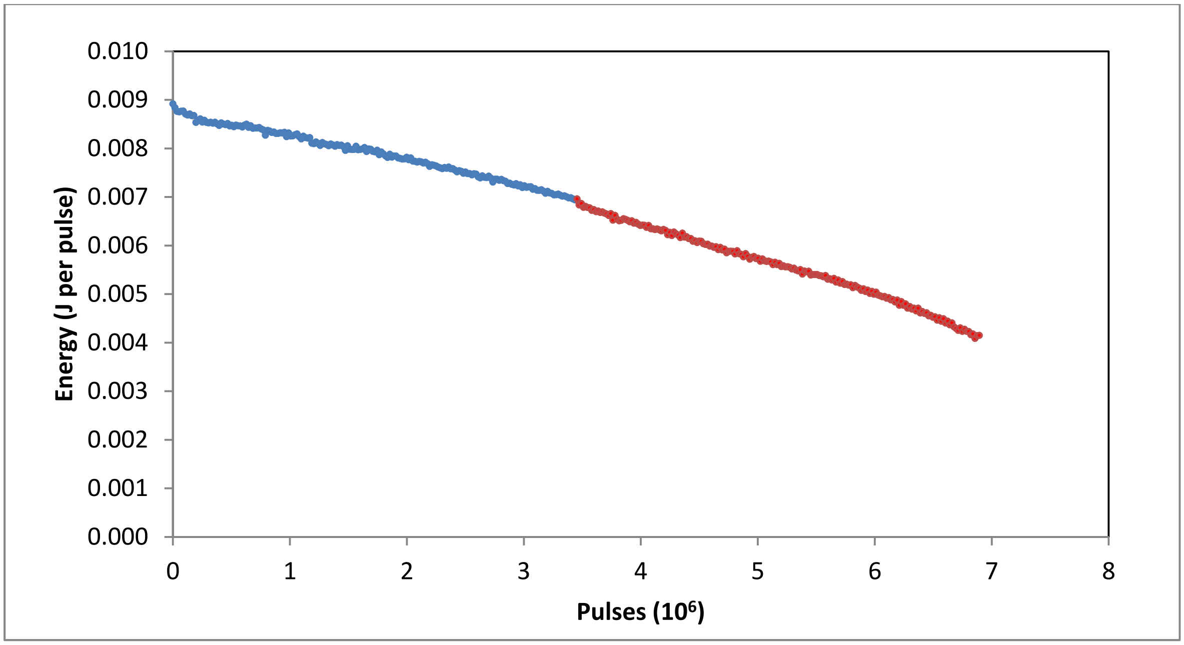

Figure 6. Ex5ALN KrF laser output energy as a function of accumulated pulses using constant voltage mode at 14 kV and 100 Hz. The output falls to half of the fresh fill level after 7 M shots.

2.3.11. Shelf-Life Test

The ability of the laser to maintain output power during periods of storage (its shelf-life) was examined. The test was carried out by filling the laser and measuring the output under fresh fill conditions (after warm=up) at 12 kV discharge voltage and 20 Hz. The system was left unused for a period of five days and then the output power was measured at 12 kV discharge voltage and 20 Hz for a nine-hour period. The system was then left unused for an additional five days and retested at 12 kV discharge voltage and 20 Hz for an additional nine hours. The data is plotted in Figure 7. At the end of 10 days the laser output had degraded to 50% of the fresh fill output, consistent with the manufacturer's specifications of a 10-day shelf-life. However, once the laser was put into service, the rate of degradation of the laser output was much faster than was experienced starting with fresh fill conditions. Notice the change in slope for the periods of use shown in the diagram.

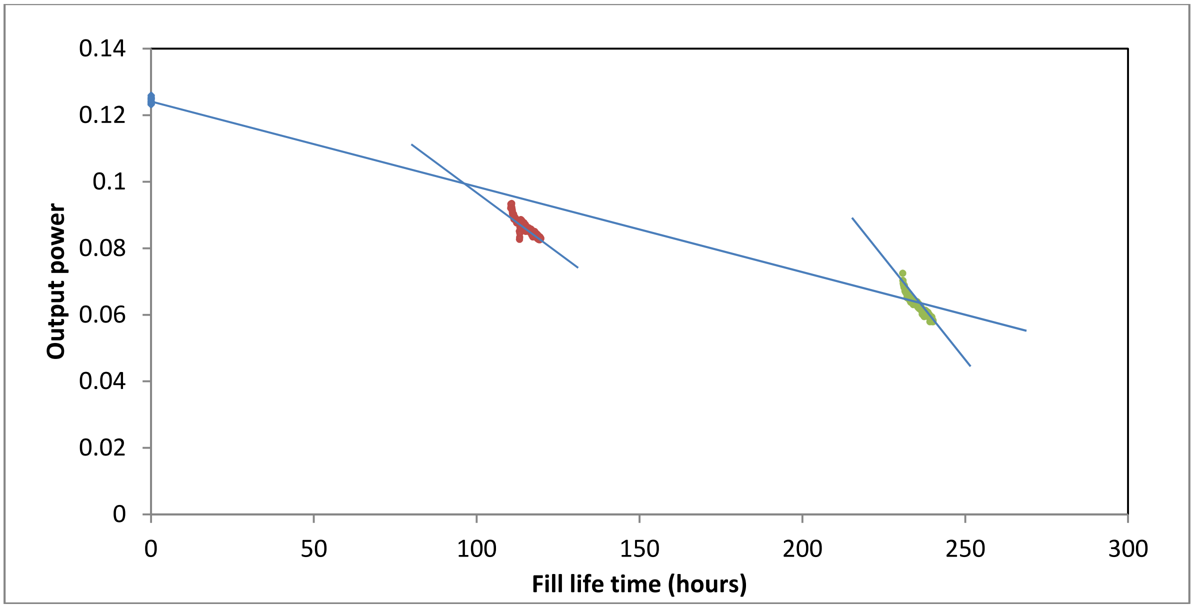

Figure 7. Shelf-life testing showing the Ex5ALN KrF laser output power as a function of hours after fresh fill. The data points indicate the output power at 12 kV and 20 Hz operation.

2.3.12 Pulse Profile Measurements

A beam profile image is shown in Figure 8. This profile was typical of those observed following delivery of the system and was consistent with all profiles obtained over the course of this test period. No attempt was made to improve the profile before or during testing. The profile image shown in the figure was obtained 1.5 m from the laser exit port using a flat glass surface to attenuate the beam by reflection from front surface. The beam was completely absorbed in the filter so that rear surface reflection would not be observed to complicate the profile. The shape was approximately rectangular with dimensions of 7 x 3 mm, similar to manufacturer specifications which were 6 x 3 mm. The profile has more intensity in the lower half than in the upper. Similar profiles could be observed visually on fluorescent paper. This profile suggests that the mirror and/or output coupler were slightly misaligned. No hot spots or arcing could be detected in any of the profiles collected over the duration of the test period.

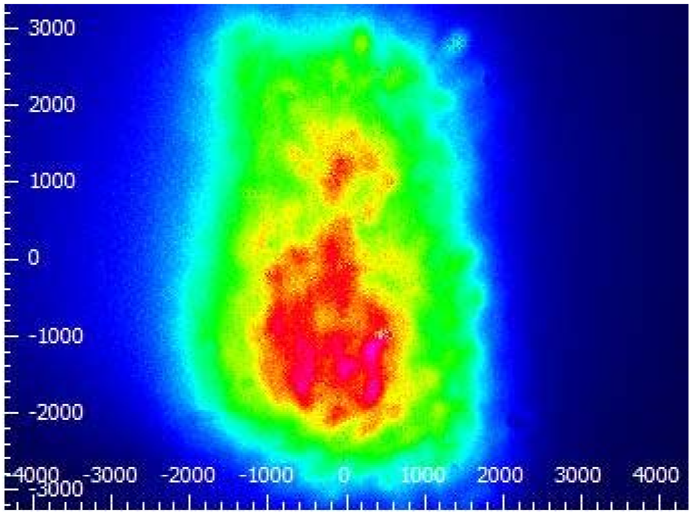

Figure 8. Ex5ALN KrF excimer laser output beam profile. Color indicates laser intensity.

2.3.13. Post-Test Inspection

During the course of this study nearly 50 M laser pulses were produced by the system. The manufacture suggests mirror and output coupler maintenance be completed after 100 M pulses. Inspection of the laser cavity (looking through the cavity using a flash light) did not reveal visible damage or deposits on the optical surfaces. The electrode surfaces appeared to be smooth and reflective with no visible pitting or defects with slight fogging near the edges. Disassembly of the laser to allow close inspection of the internal components was not attempted.

3. SUMMARY

The results of this study will be described within the context of utilizing these high-power, high-repetition-rate laser systems for spectroscopy applications. The critical characteristics for use in spectroscopy applications are the output power, pulse-to-pulse stability, laser pulse length, bandwidth, trigger jitter, pulse profile, and fill-gas lifetime. The specifications for the line-narrowed Ex5ALN KrF excimer laser system were collected in Table 1 and are compared to the results of this study in Table 2.

Observed in this work			Manufacture's Specification
Wavelength:	248.7 nm		248 nm
Linewidth	< 0.1 nm		0.020 nm
Pulse Energy	12.4 mJ at 15 kV with fresh fill		15 mJ
	8.9 mJ at 13 kV with fresh fill		
	7.5 mJ at 12kV with fresh fill		
Pulse length	9.5 - 8.5 ns depending upon fill condition		8 ns
Beam shape	3 × 7 mm at 1.5 meters from output port		3 × 6 mm
Average Power	225 mW at 25 Hz 14 kV		0.3 W at 25 Hz
	900 mW at 100 Hz 14 kV		
	2.3 W at 250 Hz 14 kV (not sustainable for long periods)		2.5 W at 250 Hz
Stability	±1.5% (1σ) fresh fill		< ±3% (1σ))
	±3% (1σ) at 50% output		
Max Rep Rate	250 Hz		250 Hz
	100 - 150 Hz sustained		
Timing jitter	<±1 ns (1σ) *see text*		±2 ns (1σ)
Fill life	7 M pulses at 14 kV:	97 hours at 20 Hz, 19 hours at 100 Hz	18 M pulses
	10 M pulses at 13 kV:	140 hours at 20 Hz, 28 hours at 100 Hz	
	17 M pulses at 12 kV:	240 hours at 20 Hz, 47 hours at 100 Hz	
Shelf life	10 days to 50% energy		10 days to 50% energy
	Note: accelerated degradation relative to fresh fill with use		
Optics service	No visible degradation after 50 M pulses		100 M pulses

Table 2. Specifications for the Ex5ALN Excimer Laser

4. CONCLUSIONS AND RECOMMENDATIONS

In general, the Ex5ALN KrF excimer laser system performed satisfactorily and in accordance with the manufacturer's specifications. The output energy was ~20% lower than the 15 mJ per pulse specification and could only be maintained for a short period of use. An 8 mJ per pulse output can be maintained for several days at 20 Hz. The ease of installation of the hardware and control software, day-to-day operation and maintenance are important to insuring the

usefulness of the laser system as a robust laser source. These are areas where improvement can be made.

The following recommendations are presented for consideration.

i) Detailed installation instructions should be provided. Installation by service personnel would not be required if adequate instructions were provided, perhaps using instructional videos.

ii) Accurate manuals for the operation and service of the laser should be provided. The current manuals have many conflicting statements and inaccuracies.

iii) Software issues must to be corrected.

iv) The primary functions of the laser (discharge voltage adjustment, repetition rate settings, and triggering) should be available for manual operation without requiring the system to be connected to a computer. An energy monitor display could also be included.

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ACRONYMS AND ABBREVIATIONS

GAM Ex5ALN	Miniature line-narrowed excimer laser manufactured by GAM Lasers, Inc.
Hz	Hertz, frequency (sec^{-1})
ICCD	Intensified Charge-Coupled Device
KrF	Krypton Fluoride
NIST	National Institute for Science and Technology
UMBC	University of Maryland Baltimore County

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